IS 5878-1 (1971): Code of Practice for Construction of Tunnels, Part I: Precision Survey and Setting Out [WRD 14: Water Conductor Systems]

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CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS
PART I PRECISION SURVEY AND SETTING OUT

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BUREAU OF INDIAN STANDARDS
MANAK BHAVAN, 9 BAHADUR SHAH ZAFAR MARG
NEW DELHI 110002

Gr 6

September 1971

Indian Standard

CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS CONVEYING WATER

PART I PRECISION SURVEY AND SETTING OUT

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Indian Standard

CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS CONVEYING WATER

PART I PRECISION SURVEY AND SETTING OUT

0. FOREWORD

0.1 This Indian Standard (Part I) was adopted by the Indian Standards Institution on 29 March 1971, after the draft finalized by the Water Conductor System Sectional Committee had been approved by the Civil Engineering Division Council.

0.2 The construction of tunnels involves a variety of problems. Because of the great longitudinal extent of the work, many different kinds of conditions are encountered which for maximum economy should be treated differently. Moreover, design of a work is based on assumptions regarding quality of work which would be obtained during construction. These assumptions hold good only if the material used and the work as actually executed are according to the specifications which are known to give desired results. This standard (with all its parts) is intended to serve as a guide to the engineer-in-charge of construction of tunnel projects. However, because of the complex nature of the subject, it has not been possible to cover all possible contingencies and the judgement of the engineer-in-charge is required in making a final choice of the method to be adopted depending upon the conditions prevailing at the site.

0.3 This Part covers methods of precision survey setting out the tunnel alignment. Since the excavation of tunnel is normally started from many faces for expedititious completion of the work, it is essential that the excavation proceeds precisely along the pre-determined alignment. Even a slight deviation from the correct alignment, particularly in the initial stages, may lead to non-coincidence of the centre lines of the various stretches of a tunnel at the meeting points.

0.3.1 Other parts of this standard are as follows:

Part II Underground excavation in rock
Part III Underground excavation in soft strata
Part IV Tunnel supports
Part V Concrete lining
Part VI Steel lining

0.4 This standard (Part I) is one of a series of Indian Standards on tunnels. Other standards published so far in the series are:

IS : 4880 (Part II)-1968 Code of practice for design of tunnels conveying water: Part II Geometric design

IS : 4880 (Part III)-1968 Code of practice for design of tunnels conveying water: Part III Hydraulic design

IS : 4756-1968 Safety code for tunnelling work

0.5 In the formulation of this standard due weightage has been given to international co-ordination among the standards and practices prevailing in different countries in addition to relating it to the practices in the field in this country. This has been met by deriving considerable assistance from the section ' Survey and Setting Out ' by George Hurst of the following publication:

Pequignot (CA), Ed. Tunnels and Tunnelling, Hutchinson and Co (Publishers) Ltd, London

0.6 For the purpose of deciding whether a particular requirement of this standard is complied with, the final values, observed or calculated, expressing the results of a test or analysis, shall be rounded off in accordance with IS : 2-1960*. The number of significant places retained in the rounded off values should be the same as that of the specified values in this standard.

1. SCOPE

1.1 This standard (Part I) covers recommendations for precision survey and setting out of tunnels.

2. INITIAL SURVEYS

2.1 The alignment of a tunnel is governed by the surface conditions, rock cover available on all sides of the tunnel, etc. In case of tunnels in hydroelectric projects, the obligatory points may be the surge wells, shafts, etc. Obligatory traffic directions may decide the portal sites for tunnels in cities.

2.2 Broad alignment of tunnels should be based on detailed topographical maps or city maps prepared either by the Survey of India or the city Survey Officials or the concerned organization incharge of the tunnel. In, out of the way locations a detailed tachyometrical reconnaissance survey of the area giving both horizontal and vertical control should be conducted.

*Rules for rounding off numerical values (*revised*).

2.3 After fixing the obligatory points like portal points, shaft location, etc, on topographical maps, the run of the tunnel may be decided. The two ends of the tunnel shall be then located on ground and the stations from which driving lines can be set out shall be fixed precisely. These portal points shall be marked by concrete pillars or by concrete blocks in the ground, defined by a cross or other marks on a brass plate or plug built into the concrete or by a 25 mm to 40 mm diameter galvanized iron pipe, 30 cm long embedded in concrete with one end about 8 mm above the top of concrete surface and with a cross cut on the top of pipe (*see* Fig. 1).

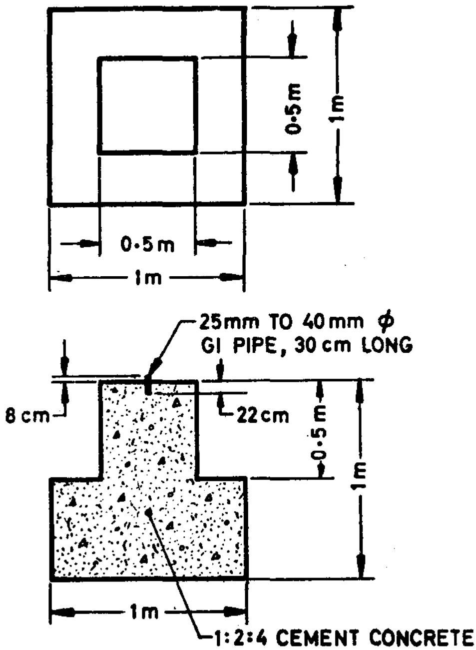


Fig. 1 Concrete Pillars

3. DIRECT SETTING OUT OF THE TUNNEL CENTRE-LINE ON THE SURFACE

3.1 It is extremely rare that the contours of the ground beneath which the tunnel is situated, are sufficiently favourable to allow one extremity of the tunnel being visible from the other. Generally, the ends of the tunnels themselves are not sightable one from another. Yet a summit point can be obtained from which points in the direction of the line of trace can be accurately determined, marked and rendered available for the alignment of the face headings, by the method of reciprocal ranging.

3.2 In open country, the approximate direction of the tunnel may be drawn on the topographical map and the direction line approximately laid out with a theodolite from one of the terminal stations (*see X* in Fig. 2), the line being extended from station to station over the intervening high ground until it reaches the other terminal station *Y*. The extension at each station shall be made by double-transiting the theodolite on both circle-left and circle-right, and the mean position shall be taken as the prolongation. In the first trial there may be some deviation, say, δ of the end of the extended line from the second terminal station *Y*. The intermediate station *Z* shall be then moved laterally by an amount δ' equal to $\delta \times \frac{XZ}{XY}$ and the extension processs shall be repeated until a straight line through *X* and *Y* is obtained. Pillars shall be erected at the intermediate stations and the whole process repeated, several sightings being taken at each intermediate station in both circle-left and circle-right positions. The mean of each set shall be taken as the true prolongation of the back line and over this the theodolite shall be centred for next stage of the extension. When the line passes exactly through both terminal stations the intermediate stations shall be finally marked.

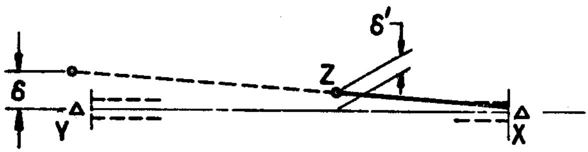


Fig. 2 Setting Out of Centre Line on the Surface

3.3 The method specified in **3.2** will not be possible in towns or open flat yet very woody area where an open or closed theodolite traverse shall be required between the terminal points. Stations shall be marked on metal plates set into curb-stones or similar constructions. The route chosen should include stations on or near to any intermediate points, where it is proposed to sink shafts near to or in the line of the tunnel axis. This will facilitate the final precise measurement on the ground from the traverse station to the tunnel axis.

3.4 For usual tunnelling, the accuracy for theodolite traverse shall be of the order of 1 in 10 000 with angular error of closure not exceeding $15\sqrt{N}$ seconds where N is the number of angles of a traverse and linear measurements are taken with the help of normal steel taps. However, fine accuracies can be obtained with the help of 1 second theodolites and accurate measurements by invar-subtense bar or invar taps.

4. TRIANGULATION

4.1 In mountainous country both the direct setting out of tunnel by reciprocal ranging or by a traverse survey is physically not practicable. Precise triangulation should be used in such cases. In other cases also a triangulation survey should be done to serve as a check on the direct alignment of the tunnel axis.

4.2 Triangulation is based on the principle that by measuring one side and angles of a triangle accurately; the remaining sides can be calculated by trigonometry. Fig. 3 shows a scheme, in which the base *QR* is very accurately, measured by subtense bar or hunter short base or base line measurement equipment, such as invar tapes or wires. By measuring each angle of each of the triangles in the layout accurately up to one second or less depending upon the availability of instruments the various sides may be calculated and co-ordinates carried on from one end to the other. At the other end the length between two known points *X*, *Y* as arrived at by calculations as above, shall be compared by actual measurements, made equally accurately as for base *QR*. The discrepancy between the two should be insignificant to prove the accuracy of the whole layout, field measurements and calculations.

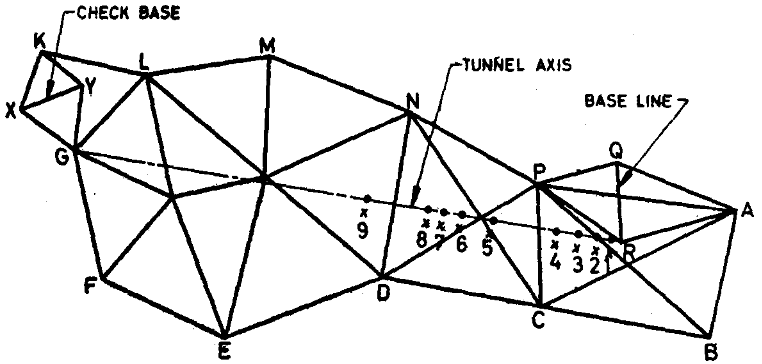


FIG. 3 TYPICAL TRIANGULATION SCHEME

4.3 If the area of a project is already covered by Survey of India triangulation, it would be possible by using the National trigonometrical stations (also called the G.T.S. stations) to obviate the time spent in measuring a base line and to reduce the amount of angular work. However, unless the surveys done by Survey of India are carried out to the tertiary stage with stations at about 3 km or so that the number of stations available may be insufficient to be of material assistance to the project.

NOTE — In such a case the initial triangulation in the area can be got done from the Survey of India, according to the importance of the scheme and cost involved. Due regard shall, however, be paid to the nature of project. What is normally required in a localized project, is the distances as measured on the surface of earth but without the true bearings. Normally the difference between the grid bearings and true bearings is insignificant in such small areas and a network of co-ordinates with true distances and grid bearings is all that is required to be established by Survey of India.

4.4 Local triangulation network should consist of geometrically sound figures namely, triangles, quadrilaterals and occasionally even polygons and the observed angles should be suitably adjusted to conform to the requirements of such figures.

4.5 The following precautions shall be taken to avoid probable sources of error:

a) The site for measurement of base line should be approximately level, evenly sloping or gently undulating and as free as possible from obstructions in order that a line of the required length may be accurately measured without undue expenditure. The base line should be as long as possible and its length should be, preferably, 1/12 to 1/15 of the total length of the tunnels to be driven, if practicable.

b) To set up a new reference point, the most desirable way is by a single triangle with no angles less than 45°. As a check, observations for another triangle should also be made. If a single triangle with any of its angles not less than 45° cannot be obtained this limit on the angle may be reduced but the angle shall not be less than 30°. This shall, invariably, be checked with another triangle. But this triangle shall not be used for further extension of the triangulation of the system. If any of these two conditions cannot be obtained in any location a braced quadrilateral should be adopted.

c) It is advisable to have two independent sets of observations done by two independent observers using different instruments and the results calculated independently and the particular set of calculations may be taken as correct only if the final results are found to agree within acceptable limits of difference as specified in **3.4**. The same criteria should be followed while setting out the alignment along the floor of the tunnels and checking it. In all these calculations, seven figure log tables shall be used and the calculations for angles shall be based on tables giving values up to one second of an angle.

d) For the calculation of angles, computation forms shall be used (a typical form is given in Appendix A).

e) For base line measurements for tunnels of smaller lengths say about 5 to 6 km, ordinary but calibrated steel tapes may be used. For longer tunnels and complicated layouts, invar tapes or wires shall be used.

f) While arriving at the true base line length, the following corrections shall be applied. At other places where the country is hilly repeated measurements in small stretch by invar-subtense bar may also be made (*see* Fig. 4):

1) Correction for absolute length,
2) Correction for temperature,
3) Correction for tension or pull,
4) Correction for sag,
5) Correction for slope or vertical alignment,
6) Correction for horizontal alignment, and
7) Reduction to sea level.

NOTE — A correction is said to be plus or positive when the uncorrected length is to be increased, and minus or negative when it is to be decreased in order to obtain the true length. It may be noted that each section of the base line is separately corrected.

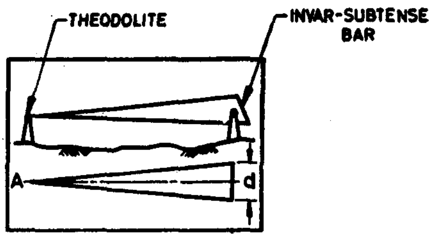


FIG. 4 USE OF INVAR-SUBTENSE BAR

4.6 Theodolites — One second or less glass arc theodolites are essential to get high accuracies in tunnelling (*see* IS : 2976-1964*). Before commencing any triangulation, the theodolite shall be tested for its permanent adjustments.

4.6.1 For measurement of angles the following procedure is recommended:

a) Set the circle and micrometer to read approximately zero on station A and take a round of readings moving in a clockwise direction. On each stations B, C, D, E and A the tangent screw shall be operated to give only a clockwise motion. On closing the single round on to station A, any permissible departure of the reading from the initial reading shall be distributed among the various angles.

b) Reverse the telescope on to the opposite face and repeat the observations, but proceeding in a counter-clockwise direction, thus completing a double round.

c) Operations (a) and (b) may be repeated say five times with initial settings at approximately 60°, 120°, 180°, 240° and 300°;

*Specification for optical theodolite.

in practice a surveyor should verify in the field, for his particular instrument, how many repetitions are necessary to obtain the required degree of accuracy.

d) After each double round the theodolite shall be re-levelled, if necessary. In mountainous country involving very steep sights, the levelling shall be carried out with reference to the most sensitive bubble, which is generally the one on the top of vertical vernier arm. The circles are best illuminated by the built-in electric lighting and care shall be taken to avoid the springs of the tangent screws becoming fully compressed or extended. For each sight, the mean of four or five micro-readings of the circle shall be obtained.

4.7 Target — Target may be, normally, a steel ranging rod inserted in a concrete block (Fig. 5) and suitably guyed, to maintain the vertical position. The design of the target merits careful study having regard to the equality and direction of the light, the clarity of the atmosphere, the type of background, and the length of sight. The best weather for surface angling is calm and moderately cloudy weather. On hot days the shimmering of the image will usually prevent angling between 1 000 h to 1 400 h. For long distances white against black shows up best and *vice versa* for short distances.

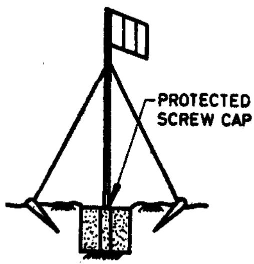


FIG. 5 TYPICAL TARGET

4.8 Degree of Accuracy in a Triangulation

4.8.1 For triangulation for small length tunnels say of 5 km or so, a minimum accuracy of 1 in 10 000 is essential though for longer tunnels much higher accuracy as in case of secondary triangulation is essential. For small localized areas and even in area of say 65 km^2, that is, even with tunnel length of 15 to 20 km error due to spherical excess is almost negligible (being of the order of 1 second for every 200 km^2). Average triangle closure for a survey of 1 in 10 000 accuracy is of the order of 5 seconds and shall not exceed 10 seconds.

NOTE — The accuracy with which approaching tunnels meet reflects the accuracy of the survey. Not only must the tunnels meet with little lateral error, but the approaching lines should make no angle with each other, though errors of a few centimetres at the holing may be distributed over a few hundred metres on either side.

4.8.2 In a triangulation network error should be propagated in the following two ways:

a) Error in the measurement of the base-line, which imparts a scale error to the whole work. This, however, has no effect on a holing, provided that no other linear measurements are involved in the project. In any case the effect is small.

b) Error in measurement of angles giving rise to error in the computed lengths of the triangle sides, and to lateral deviation of the sides from their true direction.

4.8.2.1 Utmost care shall be taken while observing the various angles and while setting out tunnel by angles. This is further illustrated in Fig. 6 and Fig. 7. Starting at the portal *A* (*see* Fig. 7), the line is run into a point *B*, where an angle *a* is turned and the line run to *C*. If there is an error in chaining, then the point will be established at B_1. But the new line B_1C_1 will be parallel to the true line *BC*. However, if an error is made in line when starting at the portal, it would give a point B_2. If the angle is then turned on this point, the new line B_2C_2 would constantly digress from the true line so much that at a distance of about 300 m the error would be 11 times that at point *B*.

4.8.3 Having observed the angles, with utmost accuracy, though the method of least squares should be adopted for adjustment of triangulation, it is sufficient to use the following methods if the angular measurements are carefully done:

a) For a triangle, the sum of all angles is 180°:

b) For a quadrilateral, (1) the sum of opposite pairs of angles is equal, (2) the sum of the circumferential angles is equal to 360°, (3) the sum of the log-sines of the left-hand angles is equal to the sum of the log-sines of the right-hand angles, looking towards the centre of the figure.

c) For other polygons:

   1) the sum of angles of each triangle is 180°,

   2) the sum of central or hub angles is 360°, and

   3) the log-sine relation is the same as for a quadrilateral.

NOTE — It is assumed that all the angles have been measured with equal care and any adjustment is, therefore, made equal on the angles concerned. It should also be emphasized that the adjustment does not necessarily make the values of the angles correct; it does, however, facilitate checking the computations when calculating the co-ordinates of stations, since any computations round a closed adjusted circuit, say *A, B, C, D, E, F, G, K* and back through *L, M, N, P, Q* to *A* (Fig. 3) should close exactly within the limits of error set by the mathematical tables employed.

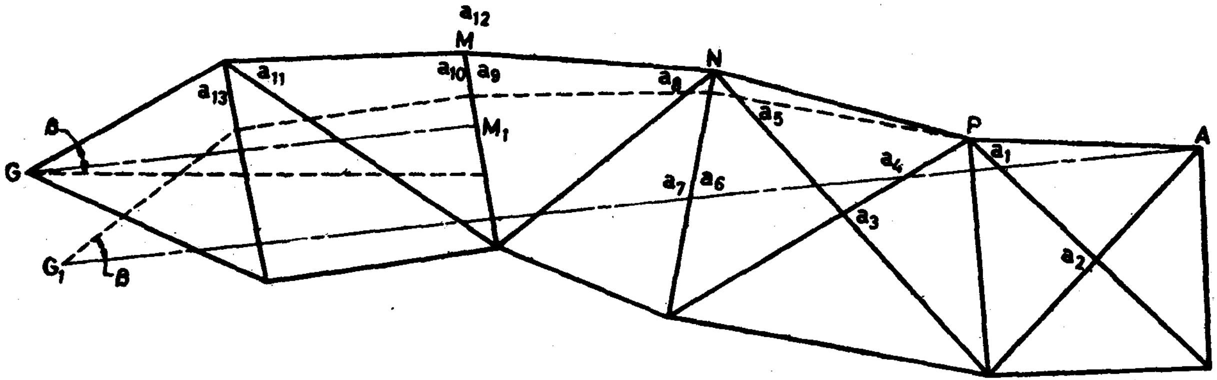


FIG. 6 PROPAGATION OF LATERAL ERROR IN TRIANGULATION DUE TO ANGULAR ERROR

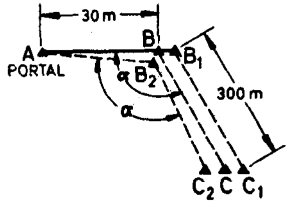


FIG. 7 EFFECTS OF CUMULATIVE ERRORS IN SURVEYING

5. LEVELLING

5.1 Instruments — For normal tunnelling a level shall be such as to be capable of giving an accuracy of ± 2 mm/km of levelling in normal country.

5.2 Precautions — Before commencing and after completing any levelling the level shall be checked for its permanent adjustment. The following precautions shall be persistently taken to avoid the many sources of error:

a) Careful focusing of diaphragm lines and staff and elimination of parallex;

b) The use of staves which are engine-divided preferably, not of sopwith staff arranged in three telescopic lengths, nor more than 3 m in length;

c) The use of a micrometer device for reading fractional parts of the 0·01 division which is helpful but not essential;

d) Limiting the length of sights to a maximum of 50 m (preferably less) and the equalization in length of the backsights and foresights;

e) The use of reliable foot-plates as turning points, where necessary;

f) Care in ensuring that the bubble is in its mid-position at the time the reading of the staff is taken;

g) Careful holding of the staff in a vertical position and avoidance of windy weather which makes this impossible;

h) Levelling within the period 1 000 h to 1 600 h in which refraction is the steadiest. At the same time this is the period when heat-shimmer is apt to be troublesome. Cool but bright weather with gentle wind is the best;

j) Protecting of the instrument by an umbrella from the direct rays of the sun;

k) Choosing such a route which permits equalization of lengths of backsights and foresights; and

m) The level survey shall be closed, preferably by repeating the levelling in the opposite direction by the same route and within a short time.

5.3 Any permissible error shall be distributed among the several stations in the proportion to the distance of the station from the starting point. With attention to these details there should be little difficulty in establishing the relative levels of the portals and of any intermediate stations on the surface of the tunnel section. At each of these stations stable bench marks shall be established.

5.4 Reciprocal Levelling — At many tunnel sites in steep mountainous country where there are precipitous slopes, normal levelling with staves is physically impossible. In such situations it is necessary to use reciprocal levelling, done by means of two simultaneous theodolite observations on two respective triangulation stations, projected distance between which is already accurately calculated.

5.4.1 *Reciprocal Observations* — In this method the vertical angle to each station is observed from the other station, and the refraction effect is assumed to be the same at each station. In order to completely eliminate the refraction effect, simultaneous observations should be taken whenever possible. It is not, however, usually possible to measure the vertical angles simultaneously. They should, therefore, be measured at the time when the refraction effect is minimum and on different days. Since refraction is less variable between 1 000 h to 1 500 h the vertical angles should be measured during these hours. The results obtained by this method are more accurate than those obtained by the method given in **5.4**. This method is explained below (*see also* Fig. 8):

Let A and C = the stations whose difference in elevation is required.

From Fig. 8:

d = the horizontal distance between A and C,

AB = the level line passing through A,

CD = the level line passing through C,

AF = the horizontal line at A (tangential to AB),

CE = the horizontal line at C (tangential to CD),

AaC = the curved line of sight,

AA' = the line tangential to AaC at A,

CC' = the line tangential to AaC at C,

$\angle A'AF$ = the angle of elevation observed at $A = \alpha$,

$\angle C'CE$ = the angle of depression observed at $C = \beta$,

$\angle A'AC$ = the angle of refraction at A,

$\angle C'CA$ = the angle of refraction at C,

$\angle APC$ = the central angle (θ),

H = the difference of elevation of A and C,

$$H = d. \frac{\sin \frac{\alpha + \beta}{2}}{\cos \frac{\alpha + \beta}{2} + \frac{\theta}{2}}$$

when the distance d is not very great, $\frac{\theta}{2}$, being very small, may be neglected. Then $H = d \tan \frac{\alpha + \beta}{2}$.

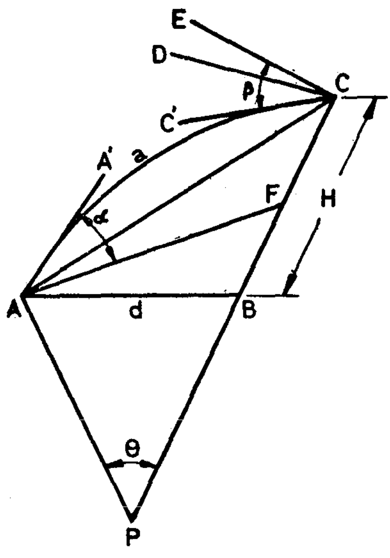


FIG. 8 RECIPROCAL LEVELLING

5.5 Plumb-Line Observations — In mountainous countries at high altitudes, the level line gets attracted towards high mountain masses. Hence, to establish the effect of such attraction due to such mountain country at high altitude out of plumb observations have got to be made and necessary corrections applied.

5.6 Automatic Level — These levels are of great help where the levelling is to be done near vibrating machines and also in tunnels where dumpers and other machinery is always playing. It ensures high accuracy and reduces the time of levelling.

NOTE — Whenever feasible use of high accuracy levels is recommended.

6. SETTING OUT INSIDE TUNNELS

6.1 Having finalized the co-ordinates of various portals of tunnels, etc by triangulation and also the relative levels of various portals, setting out of tunnels may be started from the various portals (*see* Fig. 9).

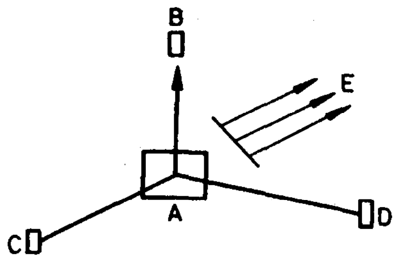


FIG. 9 SETTING OUT OF CENTRELINE OF TUNNEL

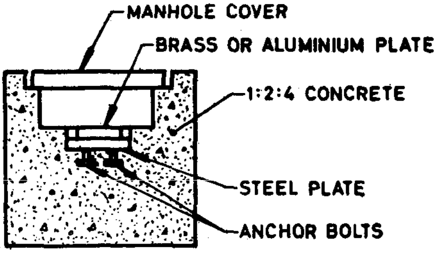
This may be done by backsighting on pillars aligned and constructed as far away as practicable on the extended centre lines such as pillar *C* and then transiting or by sighting distant pillar like *B* and turning the previously calculated angle *BAE*.

However, in the later case a second check by turning angle with reference to a certain pillar *D* is always essential. It is also essential to sight as distant reference pillars as possible, to get test accuracy.

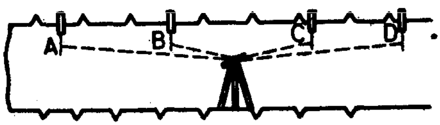
NOTE — The latest technique for alignment of tunnels is by gyro-theodolite or by laser beam.

6.2 Reference Points — In the tunnel reference points shall be constructed at about every 300 m or so. These reference points or marks may be constructed on the roof of tunnels (*see* Fig. 10), or slightly below the invert of the tunnel (*see* Fig. 10A). The pillars at the invert of tunnel shall be cast in concrete with preferably non-rusting plates fixed flush with top of concrete. These plates shall be properly protected.

6.3 Repeated observations with circle-left and circle-right shall be made to finally mark the correct alignment point on each of the reference plates. Levels of these reference marks shall be determined accurately by taking necessary precautions as given in **5.2**. All the work of finally fixing the exact alignment marks in the tunnel should, preferably, be done on holidays when the other work in tunnels is suspended or at night time by stopping vehicular traffic in the tunnels to minimize refraction errors and to achieve utmost accuracy.



10A FOR INVERT



10B FOR ROOF

FIG. 10 TYPICAL REFERENCE MARKS

6.3.1 Centre line and reference level line shall be marked on the face of tunnels for every blast to minimize errors.

6.3.2 Reference springing lines or belt lines of plaster patches at a certain convenient height above the invert, and reference chainage lines shall be marked on the sides of tunnel at about every 15 metres or so with reference to the main reference centre plates and bench marks. This will facilitate quick work on taking cross sections and other measurements in tunnel.

7. SETTING OUT STEEPLY INCLINED SHAFTS

7.1 The method for giving alignment of inclined tunnels is similar to that adopted in case of horizontal tunnels. The horizontal alignment (as in plan) of the inclined tunnel shall be fixed from upper/lower apex point. The vertical angle of its correct value of slope shall be then adjusted on the theodolite and the sloping ray marked on the heading. Levelling of both horizontal circles and vertical circles of the theodolite shall be done perfectly and while the alignment for level is being given by vertical angle of the precision theodolite, it shall be verified from time to time that the horizontal circle bubble is in the centre or is in perfect adjustment. Knowing the level of the collimation and thus the height of the collimation above the designed invert at the place of the instrument, the designed level of invert at the heading can be marked by tape. Distances shall be marked by calibrated steel tapes or with the help of invar-subtense bar.

Knowing the alignment and the invert level the excavation section at the heading can be plotted. Use of diagonal eye-piece attachment to the theodolite is of great help in the alignment of steeply inclined shafts and is recommended.

8. TRANSFERRING OF ALIGNMENT THROUGH SHAFTS

8.1 In very long tunnels or where great speed is required, work may be carried out from intermediate positions.

8.1.1 When the tunnel axis is aligned on the surface, intermediate stations are automatically aligned at the required positions. Where, however, a triangulation scheme is necessary the co-ordinates of the exact position of the intermediate stations shall be computed. The lengths and bearings of the lines connecting them to the nearest triangulation station shall be such that they can be precisely measured.

8.2 Transfer of alignment through drafts may be done by any one of the following methods:

a) Co-planing by hanging two or more plumb-lines down the shaft (*see* **8.3**),

b) Sighting directly from edge of shaft where shaft diameter to depth ratio is high,

c) By means of objective pentoprism method, and

d) By means of optical plumet and gyro.

8.3 Co-planing may be conveniently done by hanging two or more plumb-lines down the shaft and determining the bearing of the plumb-plane so formed by connecting it to the surface survey. It may be assumed that the bearing of the plumb-plane under ground is the same as at the surface, so that this becomes the starting direction for the underground survey work.

8.3.1 Two plumb lines shall be suspended in the vertical shaft as far apart as possible. They shall be of fine steel wire and each carrying a symmetrical weight of 35 kg or more. It is advisable to strain the wires up to half their breaking strength. The bobs should have projecting vanes to reduce rotation and oscillation of the wire and should be contained in a canister with a hood, which shields the bob and helps to reduce random oscillations set up by air currents or by water dropping down the shaft. It is also advisable to fill the canister with water or light oil to reduce the vibrations. In very deep shafts it may be difficult entirely to remove these oscillations; in such cases heavy bobs up to 135 kg in weight are recommended. However, their use require larger diameter wires, which make accurate bisection of the wires more difficult. Geared winches should be used to control such heavy weights. The true vertical position shall be determined either by fixing scales behind the wires and observing through the theodolite the limits of the oscillations of the bob a large number of times, and then computing the mean position; or, preferably, if the oscillations are small, by reading against a fine scale fitted in the eyepiece of the telescope. The wires shall be then clamped in the mid position by some clamping device.

8.3.1.1 A light pilot weight should be used for lowering and raising the wire in the shaft, and the heavier bob put on and taken off at the shaft bottom. It is advisable to choose a calm day on the surface unless the wire can be suitably shielded. It shall be ensured that the wires are suspended freely.

NOTE — For dropping down the wire a split washer is favoured but not certain method. A useful, but still not infallible, check is to measure carefully and compare the lengths of the wire interval both at the surface and underground. In doubtful cases it may be advisable to hang a third wire to form the three sides of a triangle.

8.3.1.2 The level shall be transferred from the vertical shaft by means of steel bands; chain or invar wires, on a calm, non-windy day. Repeated measurements shall be made to ensure higher accuracy.

9. CURVES

9.1 While setting out curves, till the tunnel proceeds for some safe length beyond the first tangent point, alignment for each blast may be given by the method of offsets from the tangent. Once the tangent point is fixed in the tunnel, the use of deflection angle method is recommended for accuracy. Wherever it is possible, it is preferable to fix apex point inside the tunnel even at the expense of some extra excavation since that will perfectly ensure high accuracy beyond the curve.

10. ADJUSTMENTS AT MEETING POINTS OF TUNNELS

10.1 If the error is less, say 25 to 50 mm, it should be adjusted in the erection of shuttering for concreting itself. If the error is of higher order, *S* curves of very large radii should be introduced near junction points.

11. CARE OF INSTRUMENTS

11.1 All optical instruments, such as theodolites, levels, etc shall be checked for permanent adjustment as often as possible. These instruments shall also be got overhauled, tested and repaired when necessary, every year during the low-work period. Optical prisms shall be often cleaned of fungus growth, which is normal source of trouble especially in coastal regions. In high humidity and heavy monsoon areas, the theodolites, levels, etc shall be kept in steel cupboards and the room should be provided with electric heaters to keep the instruments in good condition. Calibration of tapes, invar wires shall be got done. Dehumidifying chemicals, such as silicagel shall be kept in instrument box and maintained in proper conditions by heating it often.

APPENDIX A

[*Clause* 4.5, Item (d)]

CALCULATION FORMS A AND B

Calculation Form A

PRECISION SURVEY DATE

Computation of log sides of triangulation for tunnel

Station of Intersected Point	Observed Angle	△ error	Corrected Angle	Log Sines	Log Sides	See No.	Side
A							BC
B							CA
C							AB
△ No... 1 Total				K			

In grid units: (i) Log side = K + log sin (opposite angle), (ii) K = log AB + log cosec C, (iii) Enter here log cosec C (= 0—log sin C).

Computed by Date Checked by Date

Calculation Form B

PRECISION SURVEY DATE

Computation of Co-ordinates given Grid Distance and Grid Bearing

NOTE — Grid bearings are measured from North.

1.	Ref No.	Station C
2.	Station A	Station B
3.	Bearing at A of B	Bearing at B of A
4.	Corrected angle BAC*	Corrected angle ABC*
5.	Sum = Bearing at A of C = β	Sum = Bearing at B of C = β
6.	Log sin β	Log sin β
7.	Log AC*	Log BC*
8.	Sum = Log δ E	Sum = Log δ E
9.	Log cos β (β from line 5)	Log cos β (β from line 5)
10.	Log AC (line 7)	Log BC (line 7)
11.	Sum = Log δ N	Sum = log δ N
12.	Easting of A	Easting of B
13.	δ E†	δ E†
14.	Sum = Easting of C	
15.	Northing of A	Northing of B
16.	δ N‡	δ N‡
17.	Sum = Northing of C	

*From calculation form No. A.

†Positive if β is between 0° and 180° : otherwise negative.

‡Negative if β is between 90° and 270° : otherwise positive.

Computed by Date Checked by Date

AMENDMENT NO. 2 MARCH 2003
TO
IS 5878 (PART 1) : 1971 CODE OF PRACTICE FOR CONSTRUCTION OF TUNNELS CONVEYING WATER

PART 1 PRECISION SURVEY AND SETTING OUT

(*Page* 5, *clause* **2.3**, *line* 8) — Substitute '8 cm' *for* '8 mm'.

(WRD 14)